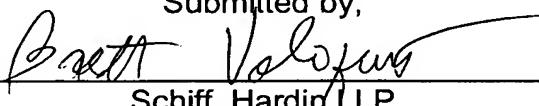


REMARKS

The specification and abstract amendments place the case in appropriate form for U.S. prosecution. Also new claims are presented based on the PCT prosecuted claims but which are drawn in accordance with U.S.
5 prosecution practice.

An Information Disclosure Statement is enclosed.

Submitted by,

 (Reg. 27,841)

Schiff, Hardin LLP

10 **CUSTOMER NO. 26574**

Patent Department

6600 Sears Tower

233 South Wacker Drive

Chicago, Illinois 60606

15 Telephone: 312/258-5786

Attorneys for Applicant.

10/550664

MARKED-UP COPY

620 Rec'd PCT/PTO 26 SEP 2005

SPECIFICATION**TITLE**

~~Method and slip for making a shaped body out of ceramic material, ceramic shaped body and use of such a shaped body~~

5 **METHOD AND SLIP FOR MAKING A SHAPED BODY OUT OF
CERAMIC MATERIAL, CERAMIC SHAPED BODY AND USE OF SUCH A
SHAPED BODY**

Description

10 **BACKGROUND**

The invention present disclosure relates to a method of making a shaped body out of ceramic material and a slip for making such a shaped body. In addition, the invention present disclosure relates to a ceramic shaped body and the use of such a ceramic shaped body.

In principle, two methods are known for making sintered ceramic shaped bodies.

First of all, it is known to press powder into the desired shape and to sinter the pressed green product so obtained in order to make the ceramic product. One disadvantage is that only limited shapes are possible. In addition, the green product shrinks during the sintering process. For this reason, a method is disclosed in EP 0 413 456 B1 according to which the ceramic powder containing silicon carbide (SiC) is suspended in ethanol, ground finer if necessary, and sifted. Afterwards, the ethanol is expelled and the powder so obtained is pressed into a green product and subsequently sintered under an oxygen atmosphere. The silicon carbide oxidizes oxidizes into silicon oxide (SiO₂) in the process and counteracts the shrinkage.

Secondly, it is known to make a slip from ceramic powder. In the process, the ceramic powder is suspended in a solvent, usually water, together with a polymeric binder. The slip is poured into a mould mold and then consolidated, in the course of which a sol-gel transition occurs and a solid body forms. This body can be removed from the mould mold without

MARKED-UP COPY

changing its shape. The body is dried, and the actual green product forms in the process, shrinking sharply as it does so. In order to reduce dry shrinkage during drying, it is freeze-dried, supercritically (under pressure) or dried under a vacuum. The freeze-drying is often carried out under a simultaneous
5 vacuum. The green product can then be sintered, in the course of which the binder escapes. One advantage of this process, which is known as gel-casting, is that very complex shapes can be formed. A disadvantage, however, is that the sintered shaped body shrinks considerably compared to the cast and green product.

10 Experiments have been carried out in order to minimise minimize the shrinkage in ceramics cast from a slip. From EP 1 122 227 A2, for example, it is known to add silicon or a mixture of aluminium aluminum and aluminium aluminum oxide to the slip. After consolidation and freeze-drying, the green product obtained in this way is sintered under an oxygen atmosphere. The
15 dimensional stability is still unsatisfactory with this process.

SUMMARY

~~Proceeding from this, the problem on which the invention is based is It is an object to provide a method of making ceramic shaped bodies which uses the advantages of gel-casting[[],]~~ in order to be able to model complex shapes
20 as well, and in which a controlled volume change is possible at the same time, while avoiding the complex drying processes of gel-casting. Another problem ~~on which the invention is based~~ is to provide a slip and a shaped body of this kind. Finally, advantageous uses ~~for should be derived for~~ ceramic shaped bodies produced in this way will be indicated.

25 ~~In order to solve this problem, To solve this problem, a metal oxide powder and a metal powder are, in accordance with the method of the invention, stirred in a colloidal sol into a slip and that the slip is then consolidated in a mould mold into a green product, and finally by freeze-gelling. Finally the green product is sintered in an active atmosphere which enables the metal powder to oxidise oxidize to form the shaped body.~~

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a flow chart of a method of making a ceramic shaped body of the preferred embodiment;

5 Fig. 2 shows a device for freeze-gelling a slip in a schematic representation;

Fig. 3 shows a scanning electron microscope image of a shaped body made by the method of the preferred embodiment;

10 Fig. 4 shows a diagram of the shrinkage of ceramic materials made by the gel-casting process plotted against the sintering temperature compared to shaped bodies produced by the method of the preferred embodiment; and

Fig. 5 shows a possible application for a ceramic shaped body of the preferred embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENT

15 For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the preferred embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device, and/or method, and such further applications of the principles of the
20 invention as illustrated therein being contemplated as would normally occur now or in the future to one skilled in the art to which the invention relates.

A central feature of the invention is that the slip manages without a binder. The gel-like green product arises solely as a result of the consolidation of the slip after it is poured into the mould mold. Specifically, the slip is cooled 25 down in the mould mold in the process to a temperature lower than the freezing point of the solvent for consolidation purposes, which may be described as freeze-gelling. What is surprising about this is that, even after the solvent has been thawed, the body retains its shape without changing its contours. The green product is now dried. Since the green product already 30 has a solid shape, this can be done under normal conditions or, in order to accelerate the drying process, at an elevated temperature. The green product

MARKED-UP COPY

retains the contours of its shape while drying. Complex drying methods, such as with gel-casting as described above, are not necessary. The green product is sintered under an atmosphere which enables the metal powder to oxidise, oxidize preferably an oxygen atmosphere. Because of the open porosity of the

5 green product, the oxidising oxidizing agent, i.e. preferably the oxygen, penetrates into the green product, so that the metal powder oxidises oxidizes. According to the method of the invention preferred embodiment, something takes place which might be described as reaction sintering. The invention preferred embodiment is based on the finding that shrinkage can be

10 reduced firstly first by avoiding the use of the binder. Secondly, shrinkage is compensated by the oxidation of the metal powder. In this context, by selecting the appropriate quantity of powder, the degree of shrinkage can be adjusted to a desired amount, which also includes zero shrinkage, or even over-compensated an over compensation. Furthermore, it has been found

15 that the ceramic obtained in this way exhibits improved mechanical properties compared to classic gel-casting. Even the green product possesses enhanced strength.

In order to improve the mechanical properties still further, especially tensile strength and impact value, a reinforcement of ceramic fibres fibers,
20 such as oxide, carbide and/or nitride fibres fibers, can be added to the slip. In order to obtain a thermally or electrically conductive ceramic, a conductive material, such as silicon carbide, can also be added to the slip. Finally the slip can also be doped with carbon or carbon fibres fibers. The carbon is burned completely during sintering, leaving behind deliberately introduced pores
25 and/or channels in the shaped body.

Furthermore, in accordance with a further embodiment of the invention, the surface characteristics of the ceramic shaped body can also be influenced during the production process. It is, for example, possible subsequently to infiltrate a substance into the green product which determines the surface
30 characteristics of the later shaped body. Silanes, siloxanes, sols, a metal melt, a glass melt and/or a slip are conceivable here. Alternatively the substance can also be subsequently infiltrated into the finished ceramic.

MARKED-UP COPY

In order to solve the problem, the slip of the ~~invention~~ consists preferred embodiment is comprised of a mixture of metal oxide powder and metal powder suspended in a colloidal sol. This slip can be sintered according to the method described above. Suitable sols are in particular silicon dioxide
5 sol (silica sol), aluminium aluminum oxide sol, aluminium aluminum hydroxide sol (boehmite) and/or zirconium oxide sol. These ought to be present in the form of a nanosol. Suitable metal oxides are in particular silicon, aluminium aluminum, zirconium, titanium, calcium, magnesium oxide and/or mullite and/or spinel. ~~for~~ For the metal powder, it is possible to use precious, semi-
10 precious or base metals and, alternatively, alloys of these metals or intermetallic alloys.

A ceramic shaped body which solves the problem on which the ~~invention~~ preferred embodiment is based is produced by reaction-sintering, under an oxidising oxidizing atmosphere, a green product made from a
15 freeze-gelled slip prepared from a mixture of metal powder, and metal oxide powder suspended in a colloidal sol.

Thanks to the a very precise moulding mold accuracy and contour retention, a ceramic shaped body of this kind can preferably be used in advantageously in aerospace engineering, microsystems engineering,
20 refractory engineering and/or casting, and especially in casting moulds molds. The ceramic shaped body of the ~~invention~~ preferred embodiment is particularly advantageous for metal casting. It is, for example, possible in this way to produce a master pattern on a precise 1:1 scale and then to take a mould of it with the slip of the ~~invention~~ preferred embodiment. In the process,
25 precisely the a precise amount of metal powder is added to the slip to ensure that the increase in volume during sintering corresponds exactly to the shrinkage of the later cast metal body. As a casting mould mold, therefore, the ceramic shaped body is then bigger to precisely the extent of the shrinkage of the metal casting. The ~~invention~~ preferred embodiment can therefore be used
30 particularly well for high-precision casting (high-precision moulding molding).

A further use can be found in the field of chromatography. It is known to use charges of ceramic powder in this field. From the above description it

MARKED-UP COPY

becomes clear that not only the degree of volume change (increase and decrease in volume and complete compensation), but also the porosity can be adjusted. This can be advantageously used to produce a monolithic ceramic shaped body with a reactive surface, such as for biotechnology, and especially for chromatography.

In addition, the invention preferred embodiment can be used very well in order to produce a composite component from a ceramic shaped body and a substrate. Ceramic components are very difficult to combine with other materials, such as metals. Thanks to the method of the invention preferred embodiment, it is now possible to adjust that the degree of volume change during sintering by adding the corresponding amount of metal powder to the slip in such a way that the ceramic shaped body is press fitted with the substrate.

The invention will now be explained in more detail with reference to an embodiment illustrated in the drawings.

Fig. 1 shows a flow chart of a method of making a ceramic shaped body with the features of the invention,

Fig. 2 shows a device for freeze-gelling a slip in a schematic representation,

Fig. 3 shows a scanning electron microscope image of a shaped body made by the method of the invention,

Fig. 4 shows a diagram of the shrinkage of ceramic materials made by the gel-casting process plotted against the sintering temperature compared to shaped bodies produced by the method of the invention,

Fig. 5 shows a possible application for a ceramic shaped body of the invention.

According to the method of the invention preferred embodiment as shown in Fig. 1, a metal oxide powder and a metal powder, such as aluminium aluminum oxide powder 100 and aluminium aluminum powder 101, are mixed at 102. This mixture is homogenised homogenized into a colloidal sol, in this case silica sol 103, and suspended into a slip. The slip is then poured into a negative mould mold for the later shaped body and cooled, with

MARKED-UP COPY

the mould mold (represented in Fig. 1 by homogenizing 104 and casting 105), to a temperature lower than the freezing point of the solvent, i.e. frozen. The temperature here ought to be well below the freezing point. In the present case, the slip is cooled with the mould mold to between -5° C and -40° C. As a
5 result, the slip turns irreversibly into a solid gel (green product). This green product can now be removed from the mould mold at 107 and subsequently thawed.

The green product is dried at 108 under normal conditions or at an elevated temperature in an air kiln and sintered at 109 under an oxygen
10 atmosphere. Because of the open porosity, the oxygen penetrates into the green product, and the metal powder ~~oxidizes~~ oxidizes. The ceramic shaped body forms.

Fig. 2 shows a device in which the slip can be freeze-gelled. The device has coolant supply lines 10 and coolant drainage lines 11 indicated
15 schematically as arrows. The slip 12, optionally with the mould mold, is placed in a cooling jacket 13, which may also be the mould mold for pouring off the slip 12 itself. The coolant causes the slip 12 to freeze and gel. A suitable coolant, if the slip is to be frozen to about -40° C, is ethanol. At lower temperatures, down to about -80° C, dry ice is suitable. At even lower
20 temperatures, liquid nitrogen is used. The temperature has an influence on the size of the crystals of frozen solvent, in this case water from the sol, and thus on the pore size.

An image of a fracture surface of the ceramic shaped body taken with a scanning electron microscope is shown in Fig. 3. The ceramic material (light)
25 and the pores (dark) can clearly be seen.

Fig. 4 shows a comparison between the ceramic material made by the method of the invention preferred embodiment and a material according to the state of the art. It can be seen that material according to the state of the art already undergoes slight shrinkage at 1,000° C. At 1,400° C, the shrinkage
30 already amounts to about 10 %, while the material produced in accordance with the invention preferred embodiment does not undergo any shrinkage.

MARKED-UP COPY

powder, such as mullite and/or aluminium aluminum oxide for example. Specifically, 50 parts by weight of aqueous silicon sol (40 wt.-% SiO₂ in 60 wt.% water) with a particle size of 14 nm and 100 parts by weight of ceramic powder are blended. In addition, there are 15 parts by weight of metal 5 powder, namely—aluminium aluminum powder or a powder of—aluminium aluminum with 5 % magnesium (AlMg5).

The slip is poured into a mould mold and freeze-gelled at -40° C. After removal from the mould mold, the green product is dried at about 70° C and sintered under an oxygen atmosphere at at least 1,000° C, especially 1,400° 10 C. In the process, the metal powder oxidises oxidizes.

If desired, it is also possible to add so much metal powder or so little oxygen that the metal does not oxidise oxidizes completely. Some metal powder then remains in the ceramic shaped body, so that the latter is thermally and electrically conductive. The same effect can be achieved if the 15 green product is sintered at a lower temperature or if the reaction is interrupted by terminating the sintering process prematurely.

Thanks to the great freedom of design with respect to the mould mold a wide range of uses are possible. The ceramic shaped bodies may, for example, be used as casting—mould molds, in refractory engineering or 20 microsystems engineering.

By doping the slip with carbon, it is possible deliberately to introduce small channels in the shaped body, so that it may, for example, be used as a heat exchanger. The carbon burns off completely during sintering and leaves behind the channels or also deliberately introduced pores. The carbon forms a 25 core, as it were, or even a large number of (microscopically) small cores.

It becomes clear from the above description that not only the degree of volume change (increase and decrease in volume and complete compensation), but also the porosity can be adjusted. This can advantageously be used for chromatography.

30 A further use of the invention preferred embodiment is shown in Fig. 5, in which a filter 14 made from of a ceramic produced in accordance with the invention preferred embodiment is pressed into a retaining ring 15. For this

MARKED-UP COPY

purpose, the slip, to which so much metal powder has been added that the green product increases in volume during sintering, is poured into the retaining ring 15 and freeze-gelled between two plate coolers by analogy with the device of Fig. 2. After thawing and drying, the green product is sintered in
5 the retaining ring 15, in the process of which its volume increases in accordance with the amount of metal powder added. The ceramic filter 14 is pressed into the retaining ring in this way.

While a preferred embodiment has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered
10 as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention both now or in the future are desired to be protected.

7

List of reference numerals:

- 10 Coolant supply line
- 11 Coolant drainage line
- 12 Slip
- 5 13 Cooling jacket
- 14 Filter
- 15 Retaining ring

Claims:

WE CLAIM AS OUR INVENTION:

Abstract:

~~Method and slip for making a shaped body out of ceramic material, ceramic shaped body and use of such a shaped body~~

ABSTRACT OF THE DISCLOSURE

5 The invention proposes In a method of making a ceramic shaped body which permits an adjustable volume change (shrinkage, zero shrinkage or increase in volume) compared to its green product. In order to solve this problem in accordance with the method of the invention,, a metal oxide powder and a metal powder are stirred in a colloidal sol into slip and that slip
10 is then consolidated in a mould mold into a green product by freeze-gelling and finally the green product is sintered in an active atmosphere which enables the metal powder to oxidise oxidize, to form the shaped body. The invention disclosure is also concerned with a slip for a shaped body of this kind and a shaped body of this kind and advantageous uses for said the
15 shaped body.